How the glass makers of the middle ages worked, and how their methods have been preserved and developed as time passed. There are descriptions of many famous types of glass ware and an account of a visit to a modern glass factory.

THE STORY OF INDUSTRY SERIES

GLASS

BY

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CHAPTER I

The Window

BROTHER DENIS could not keep his mind from straying from his devotions on this bright summer morning. Between his fingers he looked across the chancel, over the shaven crowns of the monks kneeling in the opposite stalls to where the shafts of sunlight from the east window lit the wall of newly-hewn sandstone and, passing on, gave the carved oak of the chancel screen the colour of ripe corn.

His thoughts went back 20 years to when, as a novice, he had first come to the Abbey. It was in that year that the building of the church had begun. Well he remembered when Abbot Aldred, then a man of middle age, had blessed the laying of the stone on which the high altar now stood. The Abbot had prayed to God that he might live to see the building completed. His eyes turned to the sanctuary where the old man knelt by the priest who was singing Matins, and he gave thanks that the prayer had been granted.

Brother Denis' gaze moved back to the oaken screen which divided the chancel from the nave of the church. This glorious piece of carving had taken five whole years from the life of Brother John, who knelt at his side.

He turned to the east window, whose three pointed lancets rose behind the altar almost to the lofty oaken roof. They were still without glass, and Brother Denis

could see the fresh green of the beech trees just stirring in the morning breeze, while the notes of a blackbird mingled lightly with the deep tones of the chant.

His gaze travelled to the stalls across the chancel and he caught the eye of Brother Timothy, who screwed up his nose, thrust his tongue into his cheek and winked broadly at him. Shocked and ashamed Brother Denis covered his eyes, bowed his head and fixed his mind on his devotions.

At last the service was over and the monks, two by two, made their way from the chancel through the nave to the porch which gave on to the cloisters. Brother Denis was proceeding to the refectory for breakfast when his arm was touched.

"The Father would speak with you, Brother," a young monk told him.

Retracing his steps he found Abbot Aldred standing in the nave looking towards the altar. The old man's face was alight with an almost childlike joy.

"I know of what you are thinking, Father," said the monk quietly. "That at last it is done, and you are satisfied that it was worth doing."

"Yes, my son, it was well worth doing. It is a fitting offering to God. Do you think that He also is glad as He looks, as we are doing, at these slender pillars and arches and through Brother John's screen to the great east window, with its three fingers pointing to Heaven?"

"I am sure of it, Father," agreed Brother Denis, with conviction.

"I have much to be thankful for that I have been spared to see this," went on the old man; "but Denis, there is one more thing that would make it perfect."

"You mean the window?"

"Yes; the window. If we could only get stained glass as in the Cathedral of Canterbury. Think of the morning sun shining through the blues, reds, and greens of the leaded lights." He paused, lost for a moment in thought. "But, alas, it cannot be. No one in England could do justice to the work, and our treasury is already empty. It will be 20 years before we can bring glass and craftsmen from France."

"It is too soon to give up hope, Father. It is only six months since my return from France and, as I have told you, the Bishop of Chartres almost promised me that he would send us a glassmaker."

"You are right, my son. We must still hope. We shall wait until Michaelmas, and if he does not come by then, we must have the east window filled, like the other windows, with common white English glass."

* * *

The sun was setting as a little man astride a donkey, and leading two others, passed through the gate of the abbey.

"Go tell your abbot that Lawrence le Verier is here," he commanded the aged porter.

"Very-aye, Master?"

"Verier; or Vitrearius, if Latin suits you better—Glassmaker, you noodle. Then, when you have taken me to him, see that these noble steeds of mine are watered and stabled. If you value your neck, unload the baggage carefully and do not meddle with it."

Before long the old man returned and the stranger was conducted to the guest chamber, where a meal was set before him. While he was eating Abbot Aldred and Brother Denis, unable to contain their impatience, joined him.

"My lord bishop of Chartres sends you greeting

and God's blessing, Monseigneur, and bids me place my craft at your service," said Master Lawrence, kneeling to receive the Abbot's blessing.

"Pray be seated and finish your meal, my son," insisted the Abbot. "It would be discourtesy indeed to trouble you while you are yet tired and hungry from your journey."

In spite of his intention to leave business until the following day, however, it was not long before the conversation turned to the craft of the visitor. From stained glass in general it was but a short step to the subject so near the hearts of the two monks—the great east window in the new abbey church.

"You have not brought glass with you?" enquired Brother Denis.

Master Lawrence shook his head.

"I have brought the scarcer earths to give colour to the glass, for these might be difficult to find here. For the rest, I shall want sand, beechwood, and lime."

"Sand and lime burnt in our own kiln we have in plenty," the Abbot informed him, "and the woods round the Abbey are chiefly of beech trees. You have only to ask for what you need and we shall see that it is provided."

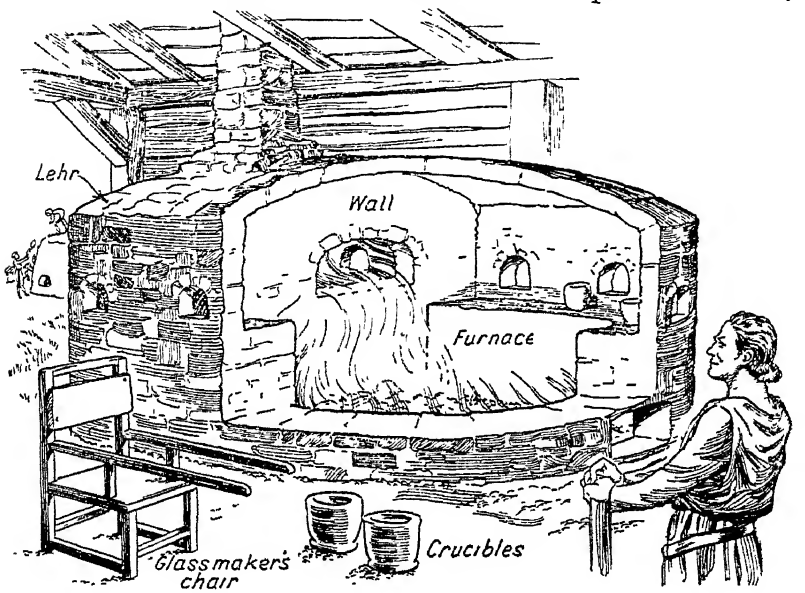
"Good," replied the Frenchman. "We can begin tomorrow."

Next morning thanks were offered to God for the timely arrival of Lawrence the glassmaker. Then the monks set to work with a will under the Frenchman's directions. Dry beechwood was gathered from the forest and stored under cover. Samples of sand were brought from far and near so that he could choose that which best suited his purpose.

Work was begun at once to construct the necessary furnaces. One of these was designed for burning the

beechwood. A second was the oven in which the glass materials would undergo their first melting. In this furnace—the calcar, Master Lawrence called it—he would also contrive to bake the crucibles, or glass-pots, so avoiding the need for an extra furnace.

Then there was the large glass furnace. So that unfavourable weather should not interrupt his labours,



Master Lawrence's Glass Furnace
It is Broken Away to Show the Inside

this was built in a disused barn. It was 12 feet long and eight feet wide, and constructed of stones and mortar, with an arched roof. There were two chambers divided by a wall running across. One of these chambers was the furnace proper, while the other was the lehr in which the glass would be slowly cooled. Halfway up the furnace chamber was a shelf of stone running round the chamber on which,

through openings in the wall, the melting-pots could be placed. Below this shelf would be the fire, stoked through a hole in the lower part of the furnace wall. The heat and fumes from the fire would pass out of the furnace chamber by an opening in the partition wall into the lehr and thence, by means of a flue and chimney, to the outside of the barn. Thus the lehr would be heated, but not to as great an extent as the furnace chamber.

A glassmaker's chair was constructed by one of the monks who was a worker in wood. It was a stool with horizontal arms which extended a yard forward beyond the seat.

After long searching, suitable clay was found to make the crucibles in which the glass would be melted. So at last, after almost a fortnight of preparation, everything was ready for Master Lawrence to begin work.

Brother Denis, who had a gift for the brush and colours, had already painted in miniature the pictures that in stained glass were to fill the three lancets of the window. The subject of all three was the Holy Mother, who was the patroness of the Abbey. In the big central lancet she knelt at the foot of the Cross on which her Son hung crucified. In the window to the left she sat in the stable nursing the Child Jesus, while in the right window she was finding the Boy Jesus talking with the doctors in the Temple.

Master Lawrence nodded approval as he examined the three paintings.

"Some small changes will have to be made here and there," said he, "for, as you will understand, the art of the stained glass worker differs from that of the painter. Each colour must have a separate piece of glass and these will be joined by strips of lead. I can

make your paintings simpler without spoiling them, never fear. Let us make the large middle window first."

The window opening was measured and its outline drawn with charcoal on the flat top of a large table prepared for the purpose. Then the two men proceeded to copy Brother Denis' picture on the table, enlarging it so that it exactly fitted the window outline.

The next stage of the work was done by the glass-maker, who divided the outline with two cross lines into three equal parts, for, as he explained, this large window would have to be made in three sections, otherwise it would not be possible to handle it without breaking when fixing it in position in the masonry. He then drew on the picture a network of thick black lines enclosing the different colours. These represented the strips of lead which would fasten together the pieces of coloured glass. The face of Mary, for example, would be made of one piece of glass; her purple robe would be another larger piece, while her blue head dress would be of three separate pieces, since it would not be possible to cut one piece of this intricate shape.

"Now," said Master Lawrence, when this long and difficult task was finished, "I know what glasses I shall require, so let us get to work and make them. First we must burn our pot-ash."

Dry beechwood was chopped small and burnt to ash in the furnace that had been built for that purpose. The ash was carefully collected so that no stones or dirt were present in it and put into a pot of water, which was boiled until all the water had evaporated, leaving the dry pot-ash or pearl ash.

Already the glass-pots had been made from refined and moistened clay in a circular shape, twelve inches

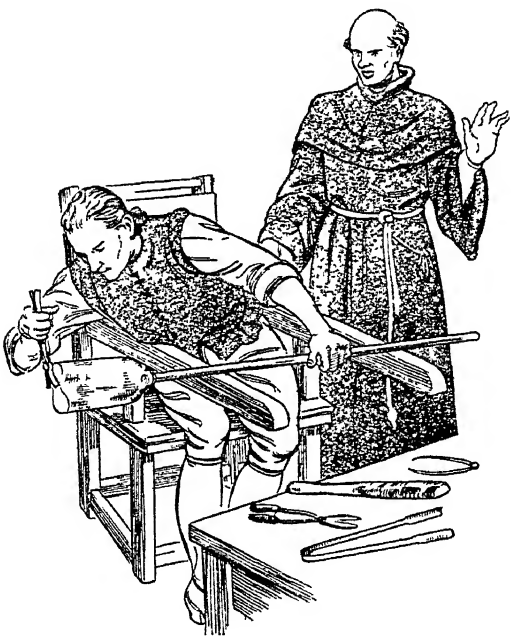
deep, eleven in diameter at the base and nine at the top, and two inches thick. They had been carefully burnt in the calcar and were now ready for melting the glass.

Sand, lime, and pot-ash were carefully measured into the pots and these were then placed in the calcar and left there until the contents were partially melted. Then the pots were removed from the furnace and the frit, as the glass at this stage is called, was poured out. When cool, it was broken up and put in pots, which were placed in the melting furnace. When the frit became molten, a scum of impurities rose to the surface and this Lawrence carefully removed. He then ladled the molten glass into pans of water. The water was poured away and the glass, which was in fragments, was dried. It was then returned to the pots ready for the final melting. It was at this stage that he added to each pot carefully judged quantities of certain of the numerous chemicals—oxides of copper, manganese, and so on—which had formed a large part of his baggage. These, he informed Brother Denis, would work together to give the glass the colours required. The pots were now placed on the shelf of the melting-chamber of the furnace and the openings through which they were inserted were blocked with clay.

After stoking the fire below with wood, Lawrence began to lay out his glassmaking tools. There was a narrow iron tube about a yard in length with a wooden mouthpiece at one end—the blowpipe. Then there was the pontee, an iron rod of about the same size. There were also tongs and shears of all sizes and shapes.

At last he judged that the contents of the pots were sufficiently melted. Having removed the clay blocks from the furnace holes and allowed the heat to die

down somewhat, so that the liquid glass began to thicken and become sticky, he drew forward the pots until they were standing near the mouths of the furnace. He now heated the end of the blowpipe in the fire. Then he dipped the heated end of the pipe into the glass, turning it so that it collected a large blob of the glass, or "metal," as the glassmaker usually calls it, much as one collects a spoonful of treacle.



With the Tongs he Pinched Together the Opposite Sides

Brother Denis watched in silent admiration as the glassblower fashioned this into a sheet of glass. Turning the blowpipe hither and thither so that the blob of metal hung evenly, he put his mouth to the other end of the pipe and breathed gently into it, swelling out the soft glass into a small bulb. Then he

swung the blowpipe like a pendulum, blowing every now and then. Slowly the glass bulb swelled to form a large bubble.

When the glassmaker judged that the walls of the glass bulb were sufficiently thin and of even thickness, he seated himself in the chair, resting the blowpipe across the projecting arms. Rolling the pipe with his left hand, he deftly shaped the bulb with a piece of charred wood and a pair of tongs with broad, flat blades, until it became cylindrical in form. He now pierced the end of the bulb farthest from the blowpipe and, with another pair of tongs, opened the hole until it was as wide as the widest part of the bulb, so forming a bell. With the tongs he pinched together the opposite sides of this opening until they almost touched to form a figure eight.

"Now pass me the pontee," he ordered Brother Denis, who removed the iron rod from the furnace where it had been heating. While he reheated the bulb of glass, Lawrence dipped the end of the pontee in the pot, picking up a small piece of glass on the end. This piece of glass he pressed to the nipped-in middle part of the figure eight to which it stuck firmly. The bulb was now attached to the pontee which formed a handle at the end opposite to the blowpipe.

The next step was to detach the blowpipe by giving it a sharp tap. After reheating the bulb, the pontee was placed across the arms of the chair and the end which had been attached to the blowpipe was opened as the other end had been. The bulb had now become a rough cylinder, which was broken from the pontee and placed in the lehr, the second chamber of the furnace.

"Glass must be cooled very gradually," Master Lawrence explained to his companion, "otherwise it could easily be shattered."

All day the work continued, cylinders of many beautiful shades of blue, purple, green, yellow, and white being blown, until the lehr was full. On the next day, when the glass had cooled, Lawrence skilfully cracked the cylinders from end to end by running a red-hot rod along the glass. They were then placed with the cracks upwards on the flat shelf of the furnace. As the glass softened with the heat, the cylinders uncurled and, assisted by the glass-maker, who spread them with an iron rod, they became flat sheets.

"Now we can return to our window," said Master Lawrence. They carried the pile of sheets of coloured glass to the table on which the sketch of the window was drawn and sorted them according to colour. Master Lawrence then proceeded to cut the glass into sheets of the required shape. Taking a piece of green glass he placed it at the bottom of the picture where Brother Denis had painted grass. The charcoal outline representing the lead strips which would later join the pieces of glass together was plainly visible through the sheet. With a red-hot iron rod the glass-maker carefully traced the outline of the leadline on the surface of the glass. The heat cracked the cold glass and Lawrence was able to break away the piece of the required shape.

"Quite easily done—when you have the trick of it," he remarked, smiling to his companion. "Long and gently curving, or straight edges are easily enough cut; but when the curves are sudden and deep it is a longer job, for the glass must be grazed away with pliers in small fragments. The most difficult part of cutting out is leaving the required narrow space between the pieces of glass so that there is room for the lead."

At last, after hours of patient work, the cutting was finished and the two men carefully laid the coloured glass on the table over the sketch.

"Now to paint it," said the glassmaker. "As you see, this patchwork of coloured glass is as yet scarcely recognisable as a copy of your picture. First, let us fix the pieces down."

Having melted beeswax in a pot, he quickly sealed the glass in position, placing a blob of wax here and there where the edges of three or more pieces came together, taking care that none of the wax came into contact with the surface of the glass, for grease would have interfered with the painting. He then carefully mixed a dark brown pigment, which, with many different brushes, he applied to the glass, sketching in the features of the faces, shading the folds of the garments and, in short, bringing to life the patchwork of coloured glass in a way which amazed the watching monk.

"Will the pigment not become worn away in time?" Brother Denis enquired doubtfully.

"We must burn it into the glass," was the reply.

Removing the pieces of glass from the table, Lawrence placed them on the shelves of a small brick oven which he himself had built with great care. Patiently he tended the fire, keeping it stoked with turf until his experience told him that at last the process was complete.

When the oven had cooled, the glass was removed and again laid out on the table. To Brother Denis' disappointment the careful brushwork seemed all to have been in vain, for the painting was sadly blurred by the firing.

"That always happens," said the glassmaker cheerfully. "Two, or even three paintings and firings are

usually needed. You can't hurry stained glass making. When you see the finished result, you will admit the trouble is worth taking. Soon we shall require lead for joining the glass together."

"There is lead in plenty left from the roofing of the church," Brother Denis told him.

As the glass, after being repainted, was again baking in the oven, they melted scraps of lead and cast it into strips of H cross section in moulds which the glassmaker had brought with him. These were then squeezed through a handmill, which made thinner and longer the soft, easily-worked metal.

At last the glass was ready, and all that remained was to fix the window together. They started with the lower of the three sections. Master Lawrence nailed thin laths of wood along two neighbouring edges of the outline and against these two long strips of lead were laid. First, the glassmaker took the piece of glass that had been cut to fit into this corner. This he pressed into the channels in the two lead strips lying at right-angles against the wooden frame. He now measured the exposed edge of the glass, cut a piece of lead to the required length and skilfully pressed this firmly into position. So, piece after piece, the window was built up, each separate piece of glass connected to its neighbours by the lead strips.

As the work proceeded the monks, and even the Abbot himself, paid frequent visits to the workshop. Now, when the final operations were being performed, Master Lawrence had around him quite a large gathering of interested spectators. At last the lower section of the window was complete.

"All that remains to do is to solder the leads and make the joins weatherproof with cement," the glassmaker told Abbot Aldred, who could scarcely

hide his impatience to see the window in position.

Where the ends of strips of lead met others, Lawrence had caused them to overlap a short distance. These joints he scraped clean with a knife blade then smeared them with tallow. He then melted a small quantity of lead in an iron pot and with a rod of metal placed a drop of this solder on each joint. The same treatment was then given to the other side of the window. Fine cement was then rubbed into the

Cutting the Shapes with a Hot Iron and Building up the Window

crevices between the lead, and the glass and the window was cleaned. The middle and pointed top portions of the window were now built up, soldered and cemented.

"Now to set it in position in the masonry," said Master Lawrence, striving in vain to hide his excitement. "We must handle the sections tenderly, for stained glass will not bear its own weight."

Already scaffolding had been set up at the east window both inside and outside the church and with the help of this the three sections of the window were carefully raised up and set in the window opening. To the intense satisfaction of the glassmaker they fitted exactly. With lengths of wire soldered to the lead the window was secured to the horizontal iron saddle bars which had been fixed every few feet across the inside of the window opening. The edges of the window were now securely cemented into the grooves cut in the stonework to receive them, and the great task was complete.

Just before sunset Brother Denis went into the church. He found Abbot Aldred standing just inside the porch looking towards the altar. Quietly the monk joined him and the two men stood in silence, feasting their eyes on the rich colours that shone like jewels from behind the scaffold poles and through the carving of Bróther John's oak screen.

"You were right, my son," said the old man at last. "I should have had faith. Is it not very beautiful?"

"I am thinking how the morning sun will light it at Matins," replied Brother Denis.

The French glassmaker remained at the Abbey throughout the autumn and winter, during which time he not only made the glass for the remainder of the east window but, as a pious gift to the patroness of the house, also a small window of extreme beauty for the Lady Chapel.

In the following year, 1226, so the ancient records tell us, one Simon de Stocha granted 20 acres of land in the manor of Chiddingfold in Surrey to Lawrence the Glassmaker.

CHAPTER II

Glass Through the Ages

DURING the long ages since man first appeared on the earth he has again and again discovered materials, which, fashioned by the ever-growing skill of his hands, have enabled him first to overcome the hardships of the weather and the dangers of attack by wild beasts and his fellow men, then to harness in his service the forces of nature.

It is of these materials, timber, stone, skins, clay, and the metals, that the world we know has been built. There is another material, which, although it has not played so essential a part in man's progress, has in the last few centuries become of such importance that it would be difficult to carry on our modern way of life without it. This is glass.

If you think of the various other materials I have mentioned, you will realise that they were favoured by man because they could be fashioned into the forms he required. Wood could be carved; flint would chip to form sharp edges; clay was plastic and easily moulded by the hands; the metals, once the difficulty of smelting them had been overcome, could be forged and cast into innumerable useful and lasting shapes. So it was with glass, for here was a material that, once the initial difficulties of its production had been overcome, could be worked like no other substance. When heated to a high temperature it became soft and obedient to the craftsman's hands—even to his

breath. It can be blown into bubbles from which vessels of many types can be made. It can be moulded into countless shapes. It can be drawn out into threads as fine as gossamer. By mixing with it certain metals it can be made to take on colours of great beauty.

Then, when the glassmaker has fashioned his obedient "metal" to his taste, it quickly becomes hard and possessed of all manner of desirable qualities. It may have great beauty of form and colour: and we must remember that from the very early days of man's history, when he painted pictures on the walls of his caves, he was concerned with the beauty of his possessions as well as with their usefulness. The surface of glass is hard, smooth and waterproof, so that it is an ideal material for eating and drinking vessels. Although brittle, it will stand very great pressure, so that in recent times it has become increasingly useful as a building material. It is an excellent insulating material and, therefore, has many uses in the electrical industry. Perhaps most important of all, it can be transparent. It is to this quality, of course, that we owe our windows, which admit light, while keeping out the cold. It is also on account of this property and because, when shaped in a certain way it bends the light rays, that by means of lenses man has been able to construct telescopes to explore the heavens and microscopes that enable him to examine and understand the tiny microbes and their effect on our health.

What is glass and how is it made? In the first chapter you have had a first glance at glass making; in the chapters that follow you will be able to examine in greater detail the processes as they have been developed in more recent times. You will find, by

the way, that surprisingly little change has taken place in glass making by hand since the Middle Ages when Master Lawrence made his windows, though wonderful machinery has been invented during the last 50 years or so to produce cheaply the commoner articles of glass that play so important a part in our lives. The second question, then—How is glass made?—will be answered in this book. The first—What is glass?—is a difficult matter even for the scientist, and I shall not attempt to do more than give you a very general answer to it.

Although in modern times many sorts of glass are made for many different purposes, the recipes being carefully worked out by chemists, we may say in very general terms that glass is made from silica, an alkali, and lime or lead. The silica is usually sand, though powdered flints can be used. The alkali is, perhaps, potash or soda. You will remember that Master Lawrence used sand, potash and lime when making the glass for his windows. Of course, many other ingredients go to make up the batch, as the glass-maker calls the mixture he puts into the glass-pot. These depend on the particular qualities required in the finished article—whether dark glass for beer bottles, clear glass for windows, optical glass for lenses, coloured glass for art purposes, heat-resisting glass for oven ware, and so on.

I shall have more to say of glass recipes when we pay a visit to a glass works in a later chapter. Here I shall merely mention that the mixture, to which is added a proportion of scrap glass known as cullet to assist the melting, is fused in a glass furnace until it is of the correct consistency for manufacture, whether by blowing or by some other process. The articles, having been formed, are then placed in the lehr,

where they are very gradually cooled, or annealed. This process is necessary because, if the glass were cooled too quickly, strains and stresses would be set up inside the material so that even the slightest tap might cause it to break into fragments.

I shall not attempt to explain why glass is transparent, except to say that it is because of the peculiar arrangement of the molecules, or particles, of which the material is made up. If you place some sugar in a pan and heat it, you will find that it turns liquid and transparent. As it cools to become a solid once more crystals form, and it is no longer transparent. If glass, or the materials that make up a glass mixture, are heated, they also become liquid, though, of course, at a very much higher temperature than is the case with sugar. When the liquid cools, it becomes solid; *but* it does so before crystals form. If crystals *do* form, it is because someone has made a mistake, and the batch is ruined. If the recipe has been properly made and the melting well done, the stickiness (viscosity) of the cooling glass increases at a sufficient rate to prevent the particles from moving together to arrange themselves in crystals.

That is as simply as I can put it: and much too simply, I hear the scientist grumble!

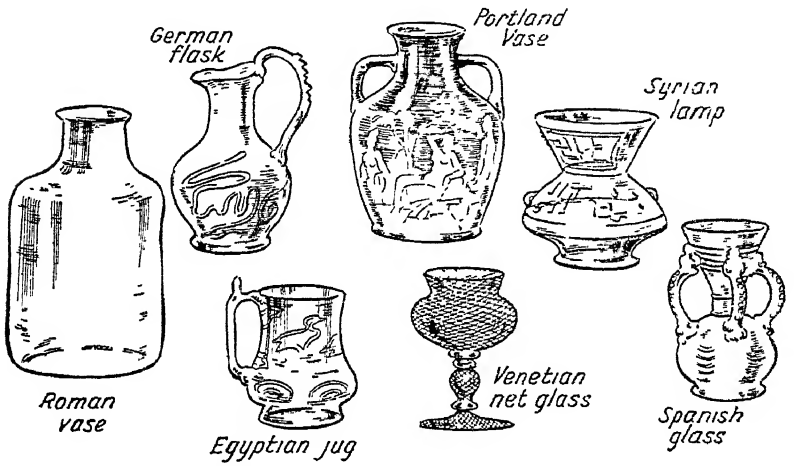
Glass is as old as the earth itself, for long before man learnt to melt together the necessary ingredients, this had been done by nature's volcanic furnaces. The commonest natural glass is obsidian, a translucent and sometimes transparent substance of blue, green, red, or brown colour, which easily breaks into long, sharp pieces. Like flints, this glass was used by primitive man to make tools and weapons. The Axtecs of Mexico made their swords, spears and knives of obsidian.

When glass was first made by man we do not know, but glazed beads have been found in Egypt dating from 14,000 years ago, and it is probable that the craft was brought there from Asia Minor. The oldest article so far found that is made entirely of glass is a piece of jewellery made in Egypt round about 7000 B.C. By 1400 B.C. there appears to have been quite a large glass industry in that country. Beads, small glass bottles, and vases were made. The hollow articles were not blown, but formed by winding a softened rod of glass round a core of hardened sand, or by dipping the core again and again into a pot of molten glass until the required thickness had been built up. In either case the core was then scraped away from the inside. Sometimes these articles were decorated by applying threads of glass to them while still hot.

About a hundred years before Christ, came a development which completely changed the manufacture of glass. This was the discovery of the blowpipe, on which a lump of molten glass could be gathered and, by the breath of the glassworker, blown into a bulb. Soon the manufacture of glass became an important industry, not only in Italy, the heart of the Roman Empire, but also in the distant colonies of Gaul and Britain. As early as the year 43 the Emperor Caligula had glass windows fitted in his palace and soon, especially in the colder parts of the Empire, window glass came into use in the homes of the wealthy. It was the glassmakers of this time who learnt how to make clear glass and practically to remove the tinge of green, which is found in early glass, owing to the presence of iron in the sand, by mixing manganese with the sand, soda and lime from which their glass was made.

The Roman glassworks produced articles of a beauty not to be equalled for many hundreds of years after the break up of their great empire. This is true not only of the ornamental bowls, jugs, and burial urns made to hold the ashes of their dead, but also of the common household glassware.

Perhaps the best known article of Roman glass is the famous Portland Vase. It is 10 inches high, of



Some Examples of Early Glass Vessels

deep blue opaque glass with white raised figures from Greek myths on its sides and base. First of all the blue body was made. Then this, while hot, was given a thick covering by dipping in molten white glass. The figures were then carved so as to stand out from the background by cutting away the white glass round them. The effect of shading was obtained by cutting down so that the thinnest covering of white glass was left through which the blue can be faintly seen.

In the fifth and sixth centuries as the barbarian peoples from Northern Europe and Asia moved southwards, even to Rome itself, the Empire of the Caesars gradually fell to pieces and for 500 years there was a period of backwardness which is sometimes known as the Dark Ages. During this period, although glass continued to be made in Europe, it was the Arabs of Spain, North Africa and the Middle East who were the most artistic craftsmen.

On the north-east shores of Italy grew up the great trading republic of Venice. Her galleys sailed to every land round the Mediterranean Sea and beyond to the great ocean of the west, and far and near through Christendom and the wide territories of Islam accounts of her wealth were on every tongue. Between 1063 and 1071 her ruler, the Doge Contarini, built to the glory of God and in honour of the city's patron saint, the great cathedral of St. Mark. For over 200 years the decorating of this magnificent church continued, almost every vessel returning to the mother city bringing from distant lands costly marbles and carvings.

The lower parts of the interior walls were plated with beautiful marbles, while above and on the vaults and domes were magnificent pictures worked in mosaic, which consisted of innumerable small cubes of coloured glass set in mortar.

It is likely that this demand for glass provided the first encouragement to the glassmakers of Venice. By the 15th century they were accepted by the civilised world as the great masters of the craft. During the growth of glassmaking there were so many glass furnaces in the city that the government, in 1291, fearing fire, ordered them to be pulled down. As a result of this law the glassmakers moved their

factories to the nearby island of Murano.

There seem to have been four separate trades, each with its guild—the window and vessel makers, the mirror makers, the bead makers, and the optical glass makers. Laws forbade sand or other materials to be exported, and so special precautions were taken to prevent outsiders from prying into the secrets of their processes. At least one case is known of a glassmaker, who, against the rules of his guild, left the city to work elsewhere, being tracked down in France and stabbed to the heart with a dagger on which was written the verdict, Traitor. So great was their wealth and standing that, unlike other craftsmen, they were accepted as gentlemen.

It is the Murano vessels of glass that are their finest products. At first they skilfully copied the designs of the gold- and silversmiths. Then they discovered their famous cristallo glass which was easily melted and very obedient to the craftsman's wishes. From this in the 15th century they fashioned wares of great beauty and of a fineness that has never been surpassed. Perhaps the most perfect examples of their work are the graceful wineglasses to which they were the first to give the form that lasts to this day.

During the Middle Ages in Europe glass went out of fashion as a material for drinking cups, the rich preferring vessels of gold and silver. Although the glassmaker's craft continued to be practised—I have already told you of the magnificent stained glass windows in the medieval churches—the vessels produced were crude compared with the beautiful work of the Romans. It was not until Venice reminded the rest of Europe what could be achieved with the blowpipe that artistic glassmaking really came into its own again.

The houses of rich and poor alike must have been uncomfortable, draughty places in the Middle Ages, for the windows, which at night were covered with heavy wooden shutters, were in the daytime open to the wind and rain. Towards the end of the period, when the nobles began to turn from war and converted their castles into mansions, windows of glass, which had seldom been seen since the days of the Roman Empire, came into fashion once more. These early windows consisting of small panes of glass fitted in wooden frames, were valued highly by their owners and it was not unknown for a noble, when going from house to house to take his windows with him in his personal luggage.

In the next chapter we shall pay a visit to a 17th century English glassworks. Let us first see how far the industry had by that time developed in our country.

Little is known of the English glass industry in Anglo-Saxon times and the later Middle Ages. Certainly most of the small amount of glass that was used in those times was imported from the Continent, though it is likely that here and there in the forests glassmakers were at work producing cups and bowls of thick, green-tinted glass. The first actual record we have of English glass making is the grant, in 1226, of land at Chiddingfold in the forests of Surrey to Lawrence the Glassmaker. This town, which is now no more than a village, appears to have been the most important centre of the small English glass industry for several hundred years, though we hear of glasshouses in other parts of the country. Rough vessels for domestic use, and window glass appear to have been the only wares produced.

In Tudor times when the turbulent days of the

belligerent barons were over and England was becoming a prosperous land, trading with many parts of the world, the fine glass from Venice was eagerly bought by the wealthy. In Queen Elizabeth's reign glassmakers from the Netherlands and Italy were encouraged by the granting of privileges to settle in England, so that fine glass might be manufactured at home instead of being brought from abroad. Before long glasshouses in which were made all manner of wares were set up in London and other parts of the country where wood for fuel was available.

In 1611 it was discovered that coal could be used as well as wood as fuel for the glass furnaces, and soon after, so great had been the wastage of forest trees, a law was made that wood must no longer be used for this purpose. The London glasshouses obtained their coal by sea from Scotland and the Tyne and the industry as a whole began to move from the wooded southern counties to the coalfields.

Since the coal fumes were harmful to the melting glass, it was now found necessary to replace the open crucibles with closed pots. As a result, since less heat penetrated to the inside of the closed pots, experiments were carried out to discover how the glass making mixture could be made to melt more easily. This was at last achieved by replacing the lime with lead oxide. The new recipe containing sand, potash and lead produced a glass, given the misleading name of flint glass, that was soon to make the English glass industry the most important in the world. This crystal glass, as it is sometimes called, was clearer and reflected the light more brilliantly than any other glass, and soon bowls, vases, drinking glasses, and mirrors made from it by the skilful English craftsmen were eagerly bought all over the world.

CHAPTER III

Mr. Lewin's Glass Works

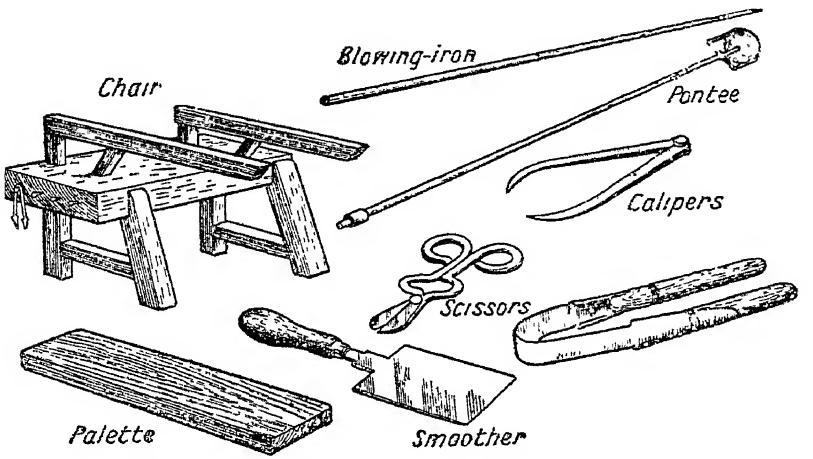
WHEN in the next chapter we pay a visit to a modern glass works, where the many articles of glass which are now so necessary to our life are manufactured, we shall find that the glassblower with his blowing iron plays a very small part in the industry. Wonderful machines turn out window glass by the acre, and bottles, tableware and electric light bulbs by the thousand. Yet the glassblower still has and always will have his place, for no machine can fashion the beautiful pieces of the artist craftsmen.

If we visited a glass works of our own time where fine glass is made, we should find that, although modern furnaces are employed to melt the glass and anneal the finished articles, yet the actual blowing and shaping of the ware is carried out in the same way—and with much the same simple tools—as were used in the 17th century and even in the Middle Ages. Remembering, then, that glassmaking by hand is today very much the same as it has been for hundreds of years, let us now pay a visit to a London glasshouse of the time of Charles II.

We make our way through the twisting cobbled streets of old London, a great part of which in two years time will be destroyed in the Great Fire of 1666, to the district of Whitechapel, and on the south side of Goodman's Yard find the "Minories" glasshouse owned by Mr. Edmund Lewin. It is a collection of

tall, dirty, stone and wooden buildings, some of them with the fronts open to the street. Over the roofs clouds of black smoke hang lazily in the warm summer air.

We flatten ourselves against the wall as a large wagon laden with sand and drawn by four horses rumbles by and turns into the glasshouse yard, where



Some of the Tools used by the Glassworker

men are waiting with shovels to unload it. At last we find the office, which occupies the lower part of a dwelling house across the street.

As we stand undecided whether to knock or make our way inside, the door opens, and a gentleman, bewigged and dressed in a blue brocade coat and knee breeches and silk stockings, comes out.

"See that those two-score wine bottles are dispatched to Mr. Pepys' house at once," he orders.

Wondering to see this fine gentleman in these dirty surroundings, we stand back hesitating; but with a smile he comes up to us.

"I'm Edmund Lewin, the master glassmaker, at your service," he announces.

We state our errand and he tells us he will be delighted to conduct us round his glasshouses.

"Those knaves in the counting house," he exclaims. "I ordered them a week back to see to the despatch of Mr. Pepys' wine bottles. I ran across him in Whitehall this morning and he taxed me with their not reaching him. The rascals will ruin my business with the Court, where, I can say with all modesty, I have a good connection."

We follow him into the glasshouse yard where workmen are unloading the wagon of sand, adding it to a large pile that is already there.

"I suppose it will be the glassblowers that will interest you most," remarks the master glassmaker. "The mixing of the ingredients is a dull enough business unless you understand the theory of it. There is the sand. The other materials, such as soda, potash and lead, we keep under cover in wooden bins."

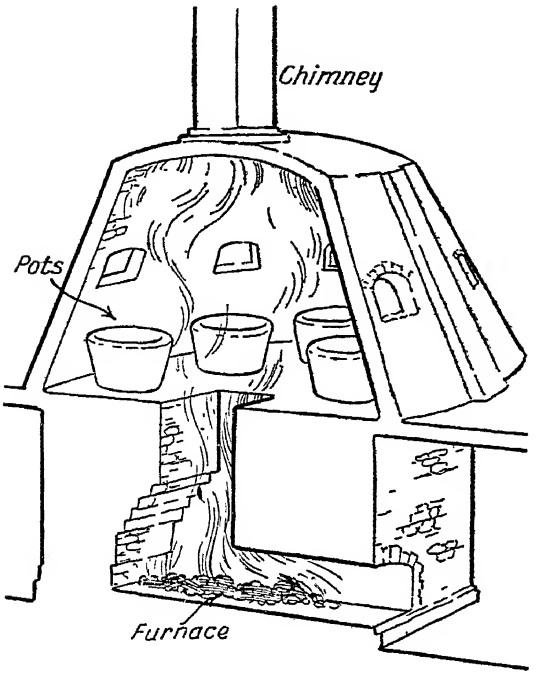
"What is this great mound of clay?" we enquire, indicating a huge pile at one side of the yard.

"That is fireclay for making the pots. Let me show you the clay-mill first."

We enter a shed in the middle of which there is a large wooden vat. Round this on a circular track a horse is being led by a boy. The animal is harnessed to one end of an overhead pole, which, as it is carried round, turns millstones in the vat, which mix the clay with water. Nearby two men are treading with their feet the clay that has been taken from the mill.

"When it has been trodden until it is even and they are sure that no stones are left in it, it is shaped in moulds into glass pots. Let us go into the kiln

house and you will see how they are baked," explains Mr. Lewin.



A 17th Century Pot Kiln

We pass into an adjoining shed and are met by the choking fumes and sweltering heat from two domed brick kilns. A workman is shovelling coal into the base of one of these. Stooping, we peer through the stoke hole into the fiery interior and are just able to glimpse the large pots that are baking there.

"So much for the pots," says the master glass-maker. "Now let us go to the furnace house, where you will see the glassblowers at work."

We enter a lofty stone building which is a veritable hive of industry. At one end of the house are two furnaces, twelve feet in height and shaped like giant beehives. They are constructed of brick, and their conical walls are strengthened on the outside with ribs of brickwork meeting at the apex, from which rises the chimney discharging the smoke through the roof of the building.

"Those are the kilns in which the glass mixture is

melted ready for the glassblowers," Mr. Lewin explains. "In the base of the furnace is the fire of coal. The teaser, as we call the stoker, feeds it through the tease holes in the lower part of the furnace wall. Above, on the first floor, so to speak, stand the pots in which the batch, or glass mixture, is melted. The pots are put in through the openings between the ribs. Higher up is the second floor which is cooler, being farther away from the fire, the heat of which passes up the centre of the furnace through holes in the two floors. The articles of glass are placed in this top story for a while before being put through the lehr."

"That is where they are annealed, isn't it?" we put in.

"The first part of the annealing is done in the upper part of the furnace, the rest in the lehr. If we did not cool the glass very gradually, strains and stresses within the material would result, so that it would break very easily or fly to pieces even of its own accord."

He conducts us to a long, low tunnel of brickwork, 18 feet long, four feet wide, and two feet in height, which extends along one side of the workshop. Both ends are open and at one end is a fire.

"This is the lehr. As you see the hot glass articles from the top of the furnace are put into the tunnel at the hot end and gradually passed through in iron pans."

At the far end of the workshop is another furnace, which, we are told, is the calcar in which the first melting of the glass mixture is carried out. We watch as an old and experienced glassmaker shovels the various ingredients into a pot, and we notice that a good deal of broken glass has gone to make up the batch.

"That scrap glass is known as cullet," explains Mr. Lewin. "It is made up of pieces broken from the ends of the blowpipes, broken vessels, and other odds and ends. We include it in the batch because it assists the other ingredients to melt."

The filled pots are placed in the calcar, where the batch receives its first melting. When this is done the molten mass is allowed to cool and is then broken up and placed in pots, which go to one of the glass furnaces. Here the second melting takes place. After the scum has been skimmed from the surface, the red-hot molten glass is poured into a vat of water. It is dried and returned to the furnace for the final melting, and is then ready for the glassblowers.

"Let us watch the bottle makers at work," the master glassmaker suggests.

With a pair of tongs a workman draws one of the pots of glass to the mouth of one of the arched openings of the furnace. The contents of the pot are at red heat and of the correct consistency for him to make his gather. Dipping the end of his blowpipe into the molten glass and dexterously twisting it as if he were collecting a spoonful of treacle, he draws it out with a blob of glass attached to the end. He turns the blowing iron in his hands to centre the glass; then, applying his mouth to the mouthpiece end, puffs down it, expanding the glass into a small bulb. He swings the blowpipe backwards and forwards so that the bulb, attempting to fly off, stretches the glass that connects it to the iron to form the neck of the bottle.

Meanwhile, the boy who assists him has placed ready a bottle mould of fireclay. The inside of this is shaped like a bottle and the mould is hinged to open into two halves. The glassblower, after reheating the bulb in the furnace, inserts it in the mould, which the

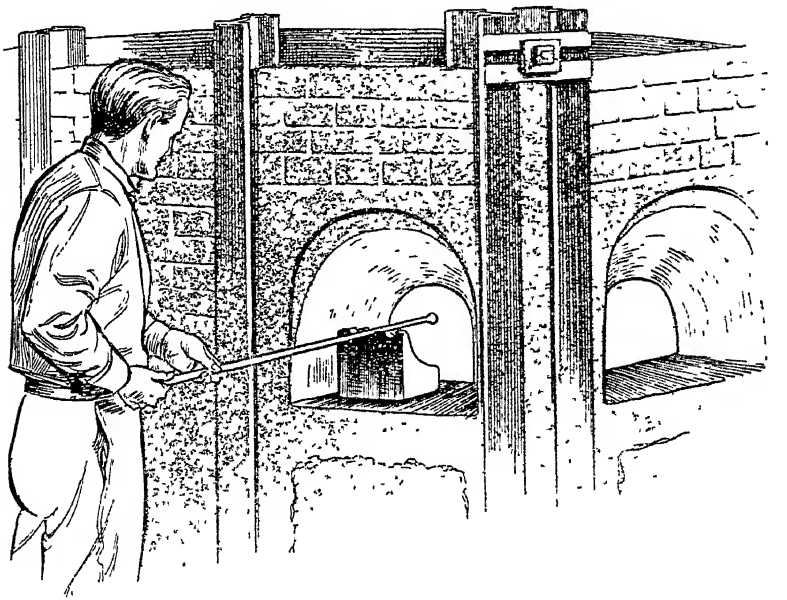
boy closes. The craftsman blows down his iron and the glass expands to fill and take the shape of the inferior of the mould. Again the boy opens the mould and the squat, black wine bottle, decorated with a round seal or prunt bearing the crest of the gentleman for whose cellar it is intended, is lifted out on the end of the blowpipe.

The glassblower's assistant has meanwhile dipped a pontee, an iron rod about the same size as the blowpipe, into the glass-pot, gathering on its end a small quantity of glass. This is touched to the base of the bottle to which it becomes fixed by the blob of glass, the bottle now being attached both to the blowing iron and to the pontee. A touch with a wet stick causes the neck of the bottle to crack away from the blowing iron. With specially-shaped shears the glass blower, holding the bottle by the pontee, moulds the mouth. Then, when he has dexterously wound a thread of soft glass round the neck to strengthen it where the cork will enter, the finished article is detached by giving the pontee a sharp tap, and the bottle is placed by the boy in the upper part of the furnace for the first part of the annealing process.

"We make bottles only for the special orders of our patrons," explains Mr. Lewin. "The bottle making industry is usually carried on in bottle houses, which are concerned only with that branch of the trade. We are engaged chiefly on wine glasses, mirrors and coach plates. Those men at the other furnace are making coach plates. These must be strong to withstand the jolting of the vehicles and we pride ourselves that they allow the passengers a good view of the countryside."

This process, the blowing of sheet glass, resembles that carried out by Master Lawrence when he made

the glass for the church window, but very much larger plates are being made. The blowpipe, which has a small knob on the gathering end, is dipped time and time again in the molten glass until a very large gather is made. After carefully centring this great blob of glass, the glassblower expands it slightly with his breath and then, with the help of tools and moulds,



"Gathering" on the Blowing Iron

forms shoulders on the bulb near its attachment to the blowing iron, thus forming one end of the cylinder. Then, standing by a pit which is sufficiently deep to allow him to swing the blowpipe with the glass at the end at full arms length, he swings the bulb like a pendulum, so that the glass, assisted by frequent blowing, gradually extends to form a cylinder.

An assistant now cuts a hole in the lower, domed end of the cylinder and the glassblower, by twirling the pipe rapidly, causes the hole to enlarge, the glass round its edge opening out to the same width as the sides of the cylinder. The cylinder is now placed on a rack, the blowpipe is knocked off and, after the shoulders have been removed, the glass is slit and taken to the spreading kiln, where it unrolls to form a flat sheet. This is taken to another workshop, where it is polished with fine sand and putty powder until it is quite transparent.

"You will admit that that is very skilful work," remarks our guide as we reluctantly leave the sheet glassblowers. "We call glass so made broad glass. There is also crown glass, which we do not make here. First, a suitable gather is made and this is blown into a bulb. A pontee is then attached to the bottom of this and the iron is knocked off. The glassblower now holds the bowl so formed in the mouth of the furnace so that the glass becomes very soft and twirls the pontee rapidly, so making the glass spread out like the skirt of a dancer to form a disc. When the pontee has been broken away and the glass annealed, small sheets can be cut from it. In the centre of the disk, or crown, is a thick piece of glass known as a bullion, which is of little use, though it is sometimes seen in cheaply-glazed windows."

We realise now the origin of the bullseyes of glass which we have seen in the windows of old houses—and also, more frequently in those that are pretending to be old. They are the centres of crowns of glass made by the process which Mr. Lewin has described to us.

"Now we come to the most interesting process of all: fine glass making," the glassmaker tells us,

leading the way to a group of men near one of the openings of the furnace. These men form a chair, or shop, and work together making wineglasses. The eldest of them, an old man with 40 years experience, is the gaffer, the head of the chair. The servitor, his assistant, is also a highly-skilled craftsman. The third member of the group is the footmaker and the fourth, the taker-in, is a boy, young in the trade, who fetches and carries, "takes in" the ware to the lehr. Their equipment consists of the chair, a wooden stool with arms projecting forward beyond the seat, a smooth, flat slab of marble called the marver, on which the glass is rolled and shaped, and a collection of very simple tools—blowpipes, pontees, wooden bats, tongs and shears of various shapes.

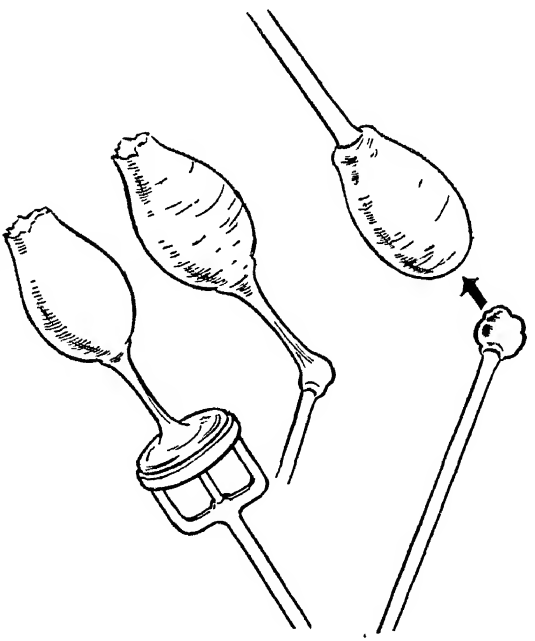
The Blob of Glass Expanded into a Bulb

Earlier the batch has been melted at a great heat in the furnace, the opening through which the glowing interior can now be seen having been blocked with fireclay. Now the heat has been reduced, the blocks having been removed, and the temperature of the "metal" as the molten glass is called, has fallen, so

that it is of the correct consistency to be worked.

The gaffer makes a gather from the pot on his three-and-a-half foot long blowing iron. Turning the pipe this way and that, he skilfully centres the blob of glass so that it is an even sphere on the end of the iron. He now rolls and shapes it on the marver, the purpose being both to shape it for blowing and to cool slightly the outer layer of glass to form a tough skin so that, when he blows, the bubble will not burst.

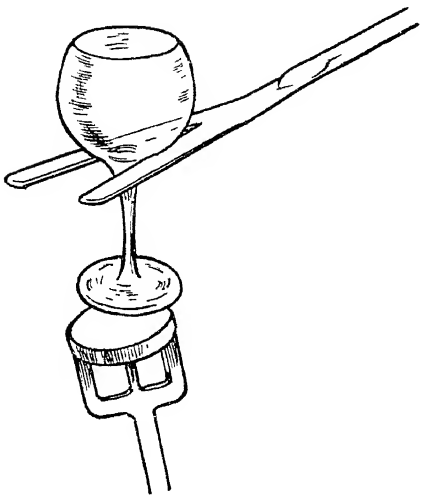
Next, he puts the pipe in his mouth and blows a bubble exactly in the middle of the blob of metal. A tough skin of glass now forms on the inside of the bulb. By tilting the end of the pipe up or down he can now cause the glass between the inner and outer skins to flow towards either end of the bulb, so regulating the thickness of the walls. In this case he holds the end of the pipe downwards, as he wishes the lower part of the wine-glass bulb to be of rather thicker glass.



The Stem of the Wine Glass is formed and Fattened Out

Then he seats himself in a chair and lays the iron across the arms,

in front of him. Rolling the pipe with his left hand, he deftly shapes the rotating bowl with a wooden bat. This, of course, is a simple example of the lathe principle.



The Wineglass Taken off the Pontee

Meanwhile the servitor has made a second gather of glass which he skilfully shapes into the stem of the wineglass. This is held near to the bowl and the gaffer guides the end to its exact position. The soft pieces of glass are touched together and unite to form one piece. On another blowing iron the foot-maker blows a small bulb, which with a tool he opens out to form a flat disc. After much rolling and shaping on the chair this is applied to the stem, which in the meantime has been reheated to receive it. The servitor now takes a pontee with a blob of hot glass on the end and applies this to the centre of the underside of the foot, to which it sticks. The glass is now cracked away from the blowpipe and the edge is trimmed by the gaffer with shears. To smooth the cut edge, the glass is held by the pontee in the heat of the furnace. Then the finished wineglass is knocked off the pontee and carried away on a forked stick to the lehr by the boy.

"These are simple enough wineglasses they are making," our friend tells us, as we express our

admiration of the skilful work of the glassblowers. "All sorts of shapes can be fashioned and decorations of many kinds can be added. For example, a bubble of air can be blown in the thickness of the stem to look like a tear. Again a bubble can be blown and stretched and twisted to form a spiral air-twist running up the length of the stem. The stem can be shaped with ornamental bulges known as knops and mereses. Then there is no end to the variety of shapes that can be given to the foot and the bowl. We can decorate the glass by engraving with a diamond point, or by cutting patterns with a grinding wheel and then polishing the cuts until they have a surface as bright as the uncut glass. English flint glass lends itself admirably to this last treatment. Again, coloured glass can be used; or designs can be painted with enamel and then burned into the surface to make them permanent. But let us move on to the packing room where we prepare our ware for despatch by wagon or on the backs of packhorses to all parts of England—and by sea to foreign lands as well, for that matter."

In the packing room Mr. Lewin's manager is examining the ware, rejecting any articles that are not perfect. The glass is then packed with straw in wooden crates, so that it will survive the jolting of the long journey to its destination.

Having dined with our kind host in his fine house in a fashionable part of London, we bid him farewell and return to the more familiar, but certainly less interesting, present.

CHAPTER IV

A Modern Glass Works

WE HAVE traced the story of glass up to the 17th century. We shall now pay a visit to a modern glassworks to see how articles of glass are produced by machinery. What of the period between the 17th century and the present day? Although in those three hundred years many improvements in the chemist's side of the craft have been made, little alteration has taken place in the manner in which the craftsman carries out glass blowing by hand. Although everyday articles of glass are no longer made by hand, yet, if we were to visit a modern glassworks where high grade vessels, such as wineglasses, are made, we should notice little difference from what we saw in Mr. Lewin's glasshouse.

Most of the wonderful machinery that has so changed the manufacture of glass has come into use only in the last 50 years. Many of the machines were used first in the United States and some of these even yet are not to be found in Britain, which has rather lagged behind America in the manufacture of glass products.

Many glass works concentrate on some particular kind of article: for example, there are bottle factories, plate glass factories, factories that specialise in optical glass, or in making table ware. If we wished to see how all these were manufactured, we should probably have to travel far and, if some of the most up-to-date

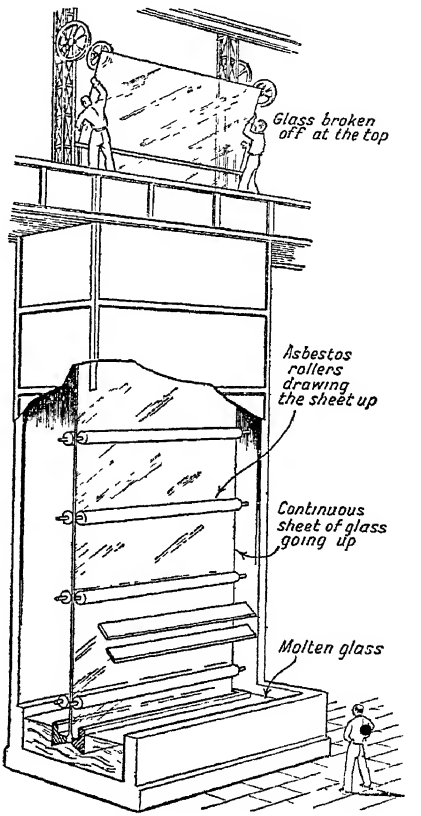
processes were to be seen, we might even have to cross the Atlantic. But our visit is to be an imaginary one, so we can easily pretend we have found a glass factory where a great many different classes of articles are made by the most up-to-date machinery.

On arrival at the works we are conducted to the office of the manager who has kindly offered to show us round.

"I hope you will not expect me to go very deeply into the chemical side of glass making," he says, "for this is a matter for the trained glass chemists, of whom we employ quite a number in our laboratories."

We reply that we already know a little about this.

"Good. You probably know, then, that from the earliest times sand, lime, and soda have been the ingredients of glass recipes. Well, although we have learnt how to add quantities of other chemicals to make the glasses we manufacture better fulfil the purposes for which they are produced, these three substances are still the principal materials



Making Sheet Glass by Machine Today

from which about nine-tenths of glass is made. Of this lime-soda glass are made window glass, glass building blocks, and practically all glass containers like jars and bottles. By the way, if we leave out the lime, we can make a glass which easily dissolves in water. This is the waterglass with which you preserve eggs and which has many uses in industry.

"Then there is flint glass in which oxide of lead is included in the recipe. Fine table ware and much optical glass are made from this. By introducing a chemical called boric oxide a most important glass has been developed which resists very high temperatures, expands very little when heated, is an excellent electrical insulator, and is not easily attacked by chemicals. This is of great value to the electrical industry, in laboratories, and in the kitchen as ovenware.

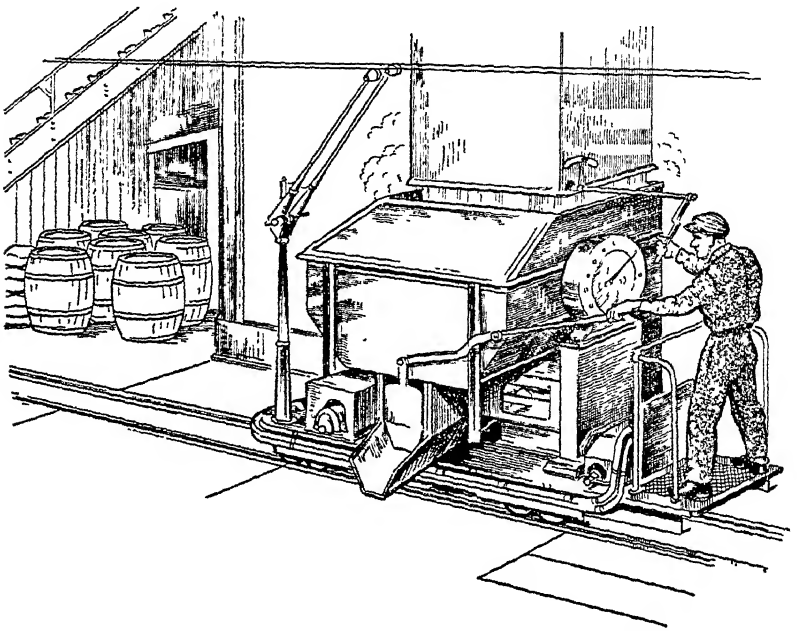
"Then there are coloured glasses of many sorts. From very early times the glass makers knew how to produce a wide range of colours by adding copper, iron, and manganese oxides to their glasses. These same chemicals and many others besides are used as colouring materials by glassmakers today.

"In case you should get the idea that all this is simpler than in fact it is, let me tell you that we use altogether about a hundred different substances to make up many mixtures. That is enough of chemistry for today; let us now see how the glass is made."

We follow him to the railway sidings, where the raw materials are being unloaded from goods trains. Mechanical shovels transfer the sand from the railway trucks to elevators, which raise it and discharge it into the tops of tall storage bins from which it can run by gravity to the mixing house to take its place in the batch. Other substances which require more careful

handling are brought to the works in bags or other containers, or in specially-designed trucks.

"As you will realise," the manager explains as we make our way to the department where the ingredients are mixed, "it is essential that the materials we use shall be clean, for the slightest impurity in, say, the

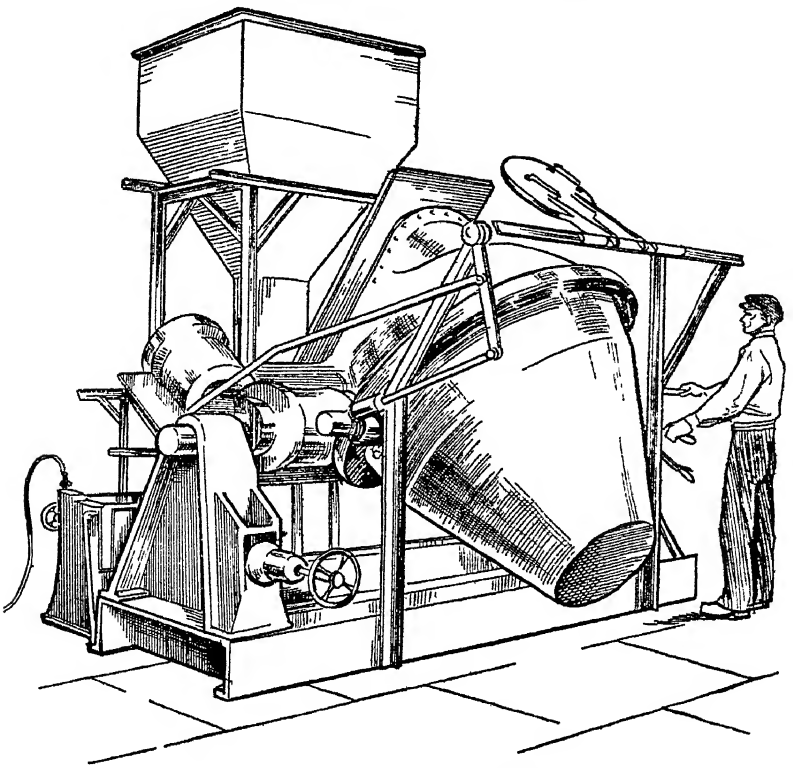


Electric Trolley collecting material from Overhead Storage Bin

sand could cause large quantities of glass to turn out discoloured and useless. Careful mixing is also very important. Before passing to the batch-mixing house the materials are screened to remove any dirt or rubbish."

In the batch-mixing house we see the row of huge bins filled by the siding elevators. Before these on rails runs a trolley into which in turn chutes discharge

the amounts of the ingredients according to the glass recipe that is being mixed. From one of the bins a large proportion of scrap glass which has been ground up, is added. Then the trolley moves off and discharges its load weighing several hundredweights into what looks like a large cement mixer. After the



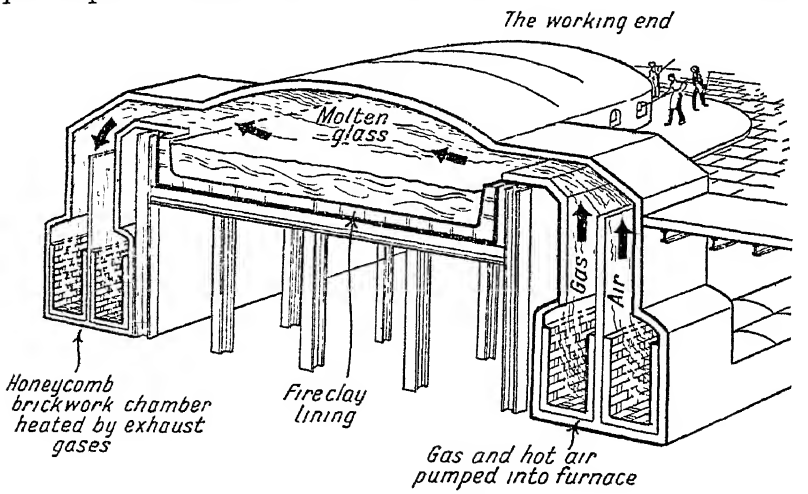
Rotation Mixer for Raw Materials

glass has been thoroughly mixed, the contents of the mixer are emptied into a wagon mounted on an electric truck, which a workman drives to the furnace.

"Before we go to the furnace house, I must tell you something about modern glass furnaces. In early

times wood was used as a fuel for heating the furnaces. Then, in the 17th century this gave place to coal. Coal has now, in its turn, gone out of date and oil and producer gas are the fuels of the modern glass works. Here we use the latter, which is generated in a gas plant in which steam is blown through white-hot coke producing the gas which is piped to the furnaces.

"These furnaces, like the open-hearth furnaces in a steel works, operate on what is called the regenerative principle. Below the furnace bed in which the glass



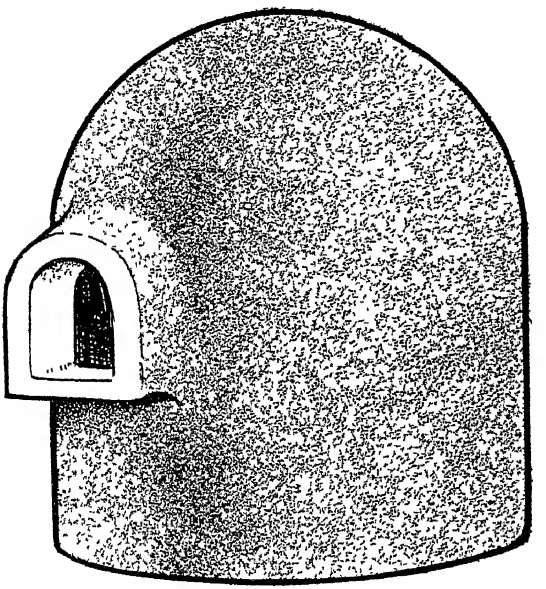
A Modern Tank Furnace

is melted are two large chambers made of honeycomb brickwork. The gas is pumped through one of these chambers into the furnace, where it burns with an intensely hot flame, the hot gases passing out to the flues through the other brickwork chamber, which is thus heated. Every 20 or 30 minutes the direction of the gas is reversed.

"There are two types of furnace used in glass works: the pot furnace and the tank furnace. In the former

the glass is melted in fireclay pots which stand on the bed of the furnace. There may be up to 20 pots in a furnace and each pot usually holds from one to two tons of batch.

"I should mention at this stage how important fireclay is in the glass industry. Since very high temperatures indeed are reached in furnaces, these must be protected with linings of fireclay which will stand the tremendous heat without cracking or melting. The queer-shaped pots with their hooded tops are also of fireclay, and are most carefully made. Much work has been done by scientists to discover what are the best clay mixtures for our purposes.



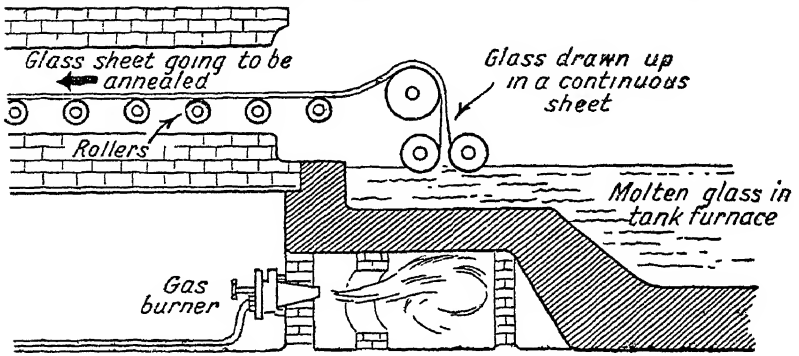
Closed Pot of Fireclay Used in Glass Making Today

"The second type of furnace I mentioned is the tank furnace, and it is one of these that you will see in a moment. Inside the furnace is a very long trough in which the glass is melted by the flames of the burning gas as they sweep across the trough. The batch is poured continuously into one end, while molten glass is continuously drawn from the other. As the material passes along the furnace it is melted

and fined—that is, the bubbles it contains are given time to rise to the surface and escape.

"Let us now go into the department where window glass is made. You will remember the old crown and hand-blown cylinder methods of manufacture. It may surprise you to learn that as recently as 50 years ago most window glass was still hand-blown by the latter process. Now come and see how we make it by the mile."

The heat is terrific in the furnace house, and we can hardly hear ourselves speak for the roar of the fires,



A Modern Method of Making Sheet Glass

the hiss of compressed air and the throbbing of machines. The great tank furnace into one end of which is fed truckload after truckload of batch from the mixers is about 100 feet long and 28 feet wide. We are told that it will hold about a thousand tons of glass. At the other end is the remarkable machine which, as our guide has told us, actually turns out window glass by the mile. When the machine was started an iron bar was lowered horizontally into the glass. It was then raised slowly, drawing up with it a sheet of glass. This was seized between a pair of rollers and the drawing continued, the sheet of glass

changing its direction from the perpendicular to the horizontal round a single roller and then being carried off on a roller track to the long annealing oven. As we watch the sheet of glass is evenly drawn from the inexhaustible furnace at a rate of about five feet a minute, hour after hour, day after day, month after month.

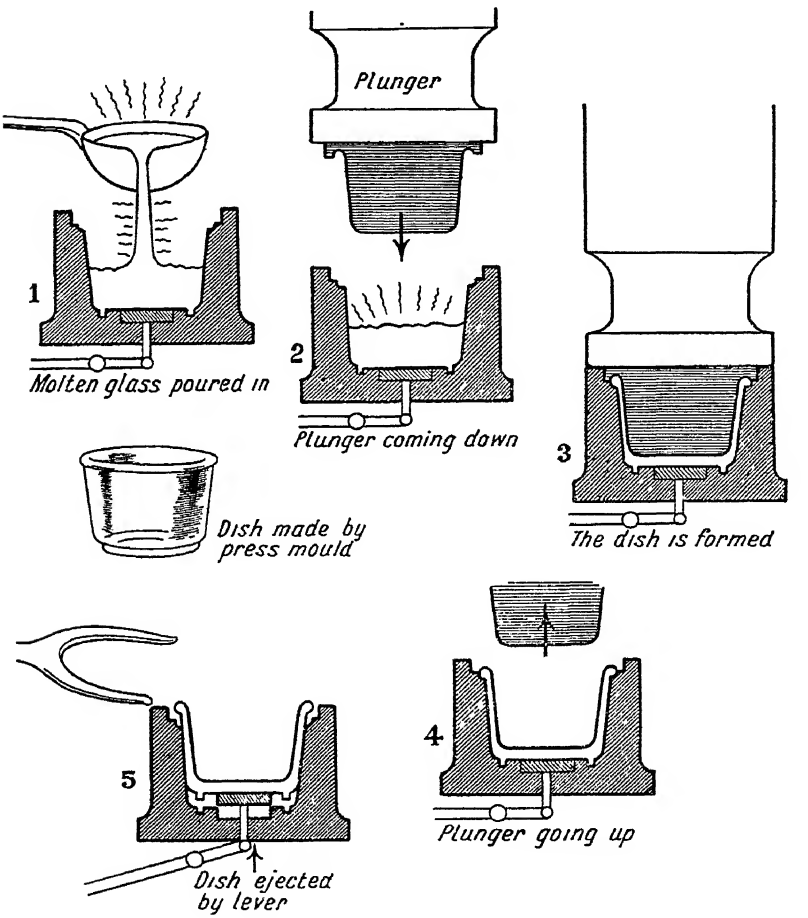
"Simple, isn't it?" smiles the manager as we watch intrigued. "Our window glass is cut to size and ready for despatch 18 hours after the raw materials reach the mixing house."

We next visit the department where plate glass is made. This, unlike the window glass, is not drawn from a tank but, in the modern machine we see, pours from the end of a tank furnace down a slope and through powerful rollers, which flatten it into a continuous ribbon, and is carried through the lehr for annealing. The ribbon is then cut into sheets. These sheets, which have a rough surface, pass to huge grinding machines, which level and polish the surface, first with coarse, then with fine, sand and finally with rouge (oxide). In this way mirror glass and plates for motor-cars and shop windows are made.

"The machine I am now going to show you," says the manager, "can be used to make bowls, tumblers, jelly glasses, ovenware, and many other similarly shaped articles. It is a pressing machine which shapes the articles by forcing a plunger down into a mould."

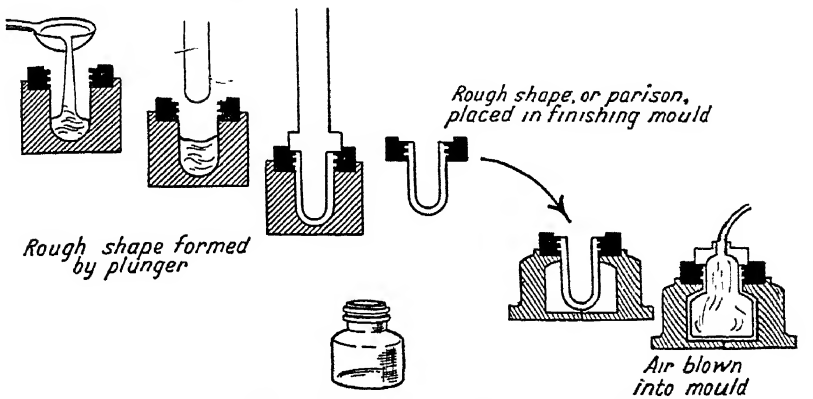
This machine rather reminds us of a merry-go-round. It has a large, circular table round which are placed at equal distances ten iron moulds, the interiors of which are shaped like the outside of an oval oven dish, which is the article being made. From the working end of the tank furnace an ingenious feeder drops a little of the molten glass down a chute into a

mould. The mould moves round and its neighbour now receives a drop of glass. We follow the first mould, however, through its ten positions, and see a plunger shaped like the inside of the oven dish press into the glass, shaping it in an instant. For the next



Press-Mould in Operation

three moves the newly-made dish cools; then it is automatically removed and carried off on a belt to the lehr. Meanwhile, the mould which it occupied moves on, cooling as it goes, to receive another drop of glass from the feeder and to begin the process all over again. This is happening, of course, to all ten of the moulds, so that a continuous procession of dishes is leaving the machine.



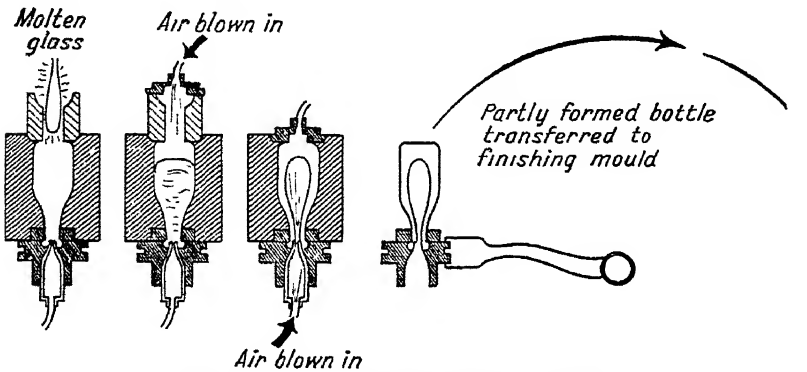
Press and Blow Method of Making a Glass Jar

"So much for pressing. Now let us see how jam jars are made," our guide suggests. "The machine you will now see is known as a press and blow machine, since the rough shape, or parison, as we call it, is first pressed, the process being completed by blowing this into a mould."

In this machine a drop of glass is delivered from the furnace into the parison mould. A plunger now descends into the mould, pressing the soft glass and filling the mould to the top to form the rim of the jar. The plunger rises and the mould falls away; another, this time the shape of the jam pot, takes its place. Compressed air is now blown into the hollow glass, which expands to fill the mould and take its shape.

This mould now falls away and the finished jam pot passes to the lehr on a conveyor-belt. There are several of these machines each turning out about 50 jam pots a minute.

In the next department we examine the bottle machines. Here, since the bottle neck is narrow, it is not so easy to give the glass its first rough shape by means of a plunger. A drop of glass is fed into the mould from above and this is forced into the lower

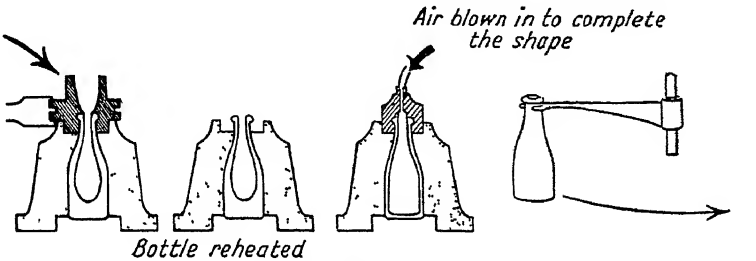


The First Stage in Shaping a Bottle

part of the mould by compressed air blown in through the top of the mould. Air is next blown in from the bottom to form a narrow hollow running about two-thirds of the length of the bottle, so making the neck and beginning the hollow of the bottle body. The glass parison is now lifted into the bottle mould by an arm which grasps the already formed neck, where compressed air blows the finished bottle which then passes to the lehr.

"Let me now show you the most wonderful glass making machine of all, the American Corning ribbon machine, which makes electric bulbs, radio valves, or thin tumblers," says our guide.

This wonderful machine can turn out more than ten articles a second! From its own continuous tank furnace a worm of glass an inch in diameter passes between a pair of water-coloured rollers, one of which is smooth, while the other has cup-shaped depressions evenly spaced round it. The glass comes from these rollers with a flat upper surface like a ribbon, but underneath are small round domes at regular intervals along its length. This ribbon is received on an endless belt along which are holes an inch or more in diameter into which the glass domes fit. As the belt moves on,



The Final Stages

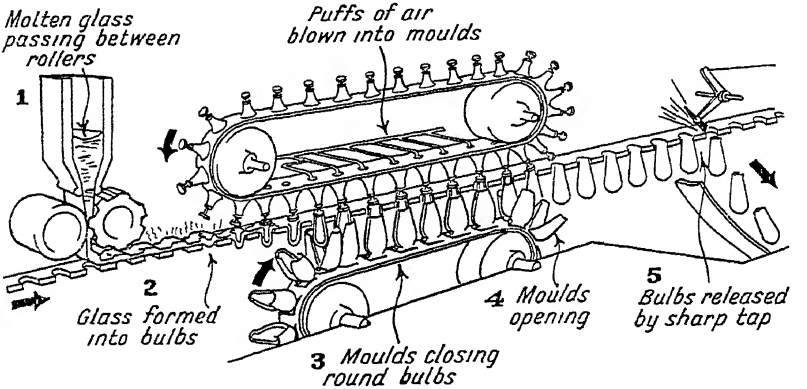
the domes, being of soft glass, sag downwards through the holes, becoming pear-shaped bulbs.

Revolving moulds carried on another endless belt below now rise up to enclose the bulbs. These moulds are lined with wet charcoal. Above these, air-pumps, moving on with the belt, close over the openings of the bulbs and blow the glass out to take the shape of the moulds. As the hot glass comes in contact with the wet charcoal lining, a cushion of steam forms, so preventing the walls of the moulds from marking the glass surface.

Then the moulds divide and the bulbs, hanging from the holes in the steel belt that has carried them through the machine, pass on to receive a tap by a small hammer, which detaches them. A belt now

carries them in a continuous stream through the annealing oven.

"The last machine I am going to show you is one for making glass tubing," the manager tells us. "Glass tubing has many uses—in laboratories, for scientific instruments, such as the thermometer and the barometer, for water gauges on boilers, and even for drain pipes. Until quite recently it was drawn by hand. A workman made a gather on a blowing iron, which he marvered until it had the shape of a cone



Bulbs Being Made by the "Ribbon" Method

with a flattened top. Into this he blew a cavity. Another workman then fastened a pontee to the flat apex of the cone and the two men moved apart, the blower occasionally puffing into the pipe to keep the interior of the tube even in shape. This is a slow and inaccurate method, and now tubing and rod, which was made in a similar way, are turned out rapidly by machine, as you will see."

The glass tube machine is quite simple in principle. Glass from a tank furnace runs in from above round a sloping, tapered fireclay tube which rotates, and through which compressed air is blown, forming the

tubing which travels several hundred feet over rollers to a belt which pulls it onwards and delivers it into the lehr. In this way a continuous tube of glass is produced which is automatically sawn into lengths and packed ready for sale. Glass rod is made in a similar way, the rod machine, however, having no blowing apparatus.

We enquire how thermometer tubing with its red and white lines is made.

"That is a very skilful and interesting process," we are told. "A gather is made on a blowing iron and this is marvered into a long cylinder into which a channel is blown. Then strips of red and white glass are laid by hand on the cylinder, which is then put into a machine which draws the tube as finely as required.

"Now you have seen most of the processes of glass-making which are carried on in this works. There are others, of course, such as the making of optical glass for lenses to be used in spectacles, telescopes, and other scientific instruments. Optical glass making is a very complicated business which is usually carried out by firms that specialise in this branch of the industry.

"Then there is coloured glass for art purposes, which is hand blown very much as in the olden days. Then again there is the safety glass which is used in the windows of motor-cars. This will not fly into splinters because it is composed of two layers of glass with a third layer of a flexible plastic material sandwiched between.

"You will remember that I mentioned two types of glass furnace—the pot furnace and the tank furnace. Today you have seen only the latter in operation. Pot furnaces are used when smaller quantities of metal are melted and when continuously-operating auto-

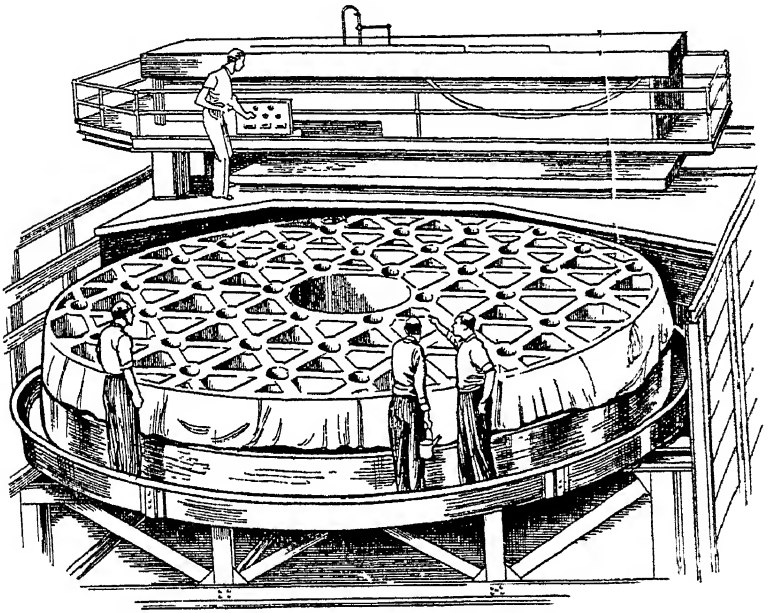
matic machines are not being fed. Optical glass, for example, is melted in pot furnaces and so is that required by hand blowers, who, of course, are still employed to make fine tableware and special articles which are not produced in sufficient quantity to make it worthwhile to set up special machines. Most of this latter sort of hand glass blowing is, of course, done with the help of moulds which assist the worker to form the articles.

"One interesting glass product I must mention. This is fibre glass, which has only quite recently come into general use for making glass wool, which resembles in appearance cotton wool. This fibre glass is useful for insulating material to keep out heat or cold, for filters, and even for making beautiful silk-like dress materials. Only recently have machines been invented which will draw out huge quantities of glass in wispy threads as fine as gossamer.

"In one type of fibre glass machine the melted glass, as it is forced out of tiny holes, is caught by a very powerful blast of gas or air which draws it out in wisps of extremely fine threads about nine inches in length. These fall like snow on a conveyor belt which carries them off to be processed ready for spinning and weaving or manufacture in some other way. In the other type of machine the glass is forced through groups of about a hundred very small holes. From these it is wound on to spindles at a speed of about a mile a minute. These glass fibres are 15 times finer than a human hair.

"Before we pass on to the decorating and packing department, I must mention one more glass making process—casting. The molten glass is either poured from pots or ladled from a tank furnace into moulds, whose form it takes, or, in the case of the older method

of making plate glass, on to an iron table where it is rolled into sheets by massive steel rollers. Glasses for lighthouse lanterns are cast in moulds. The glass disc for the huge telescope at Mount Palomar Observatory in California, which was made at the Corning Glass Works, New York, is the largest article of glass that has so far been cast. This tremendous piece of glass weighs 20 tons and measures



Polishing the Mount Palomar Telescope Mirror

201 inches in diameter and 26 inches in thickness. The special glass was melted in a tank furnace and then ladled into the huge circular mould in a casting oven, where it was heated by gas for several hours to allow any bubbles that might have remained in the glass to rise to the surface and escape. Then the disc was transferred to the specially built annealing oven,

where it remained cooling for 12 months. Two attempts had to be made before a perfect disc was produced. When the disc had been ground perfectly truly and polished, it was transported to the observatory in a special railway truck."

We move on to the departments where the finishing and decorating processes are carried on. Rough or sharp edges, where the articles have been cracked off the blowing pipes, are smoothed with hot flames, and unwanted parts are cut away by applying heat to the cold glass. We watch a sandblasting machine which, by compressed air, blows a stream of coarse sand against sheet glass, roughening the surface and making it opaque to form frosted glass. Names are stencilled on chemists' bottles in the same way.

Another method of decorating glassware is by etching. The glass is first coated with wax or resin and through this the design is scratched with needles. The article is then dipped in a bath of hydro-fluoric acid, which eats into the glass where it is unprotected by the coating. Tumblers are being etched in this way by an ingenious machine.

The most interesting process in the decorating department is cutting. Highly-skilled workers first lay out the design on the glass with a small brush and special ink. The glass article—perhaps a salad bowl made from sparkling flint glass—is then held in the craftsman's hands while the design is cut in the glass by a slowly revolving sandstone wheel. The rough surface is then polished with felt wheels and fine putty-powder. Cheaper glass is cut by machine.

The last department we visit is where the ware is carefully inspected and packed ready for despatch.

"On a short visit such as this, you can expect to obtain only a general idea of modern glass making,"

says the manager as we return to his office. "So numerous are the purposes for which glass is now-a-days used, and so complicated are the problems and processes involved in producing exactly the right article, that to understand the glass industry fully takes practically a lifetime of study and experience."

* * *

That is the story, or rather part of the story, of glass, for there is much, such as the complicated processes of optical glass making, and the hundred and one sorts of glass the scientist has devised for special purposes, that has had to be left out. We have only to think of the commonplace glass articles which play so important a part in our lives today, of the wonderful advances in science made possible by the microscope and the telescope which depend on glass for their lenses, and of the beautiful objects of glass which help to make life pleasant, to realise how important is this industry, which, though its history stretches back through thousands of years, has only grown up in the last fifty to be one of our greatest industries.

THINGS TO DO

Chapter I

1. Find out the meaning of the following words: chancel, stall, sanctuary, nave, aisle, transept, porch. Draw a plan of a church naming these different parts. Mark the position of Brother John's screen and the window for which Master Lawrence made the glass. What were the cloisters and refectory of an abbey?

2. If you examine a piece of church window glass, you will find that, while one side is smooth, the other is covered with tiny pock marks. Why is this so?

3. From the description given draw a picture of Master Lawrence's glass furnace. Make a list of the processes he used when making the window.

Chapter II

1. What do the following words mean? Anneal, translucent, transparent, opaque, obsidian, molecule.

2. Make a list of as many different articles of glass as you can remember. Opposite each state why glass is the most suitable material for the article. Then, supposing that there were no glass, suggest for each article a material that could be used instead.

3. In a museum or from among the illustrations of books on glass collecting which you will find in the Public Library, find examples of glassware of ancient Egypt, the Roman Empire, England in the Middle Ages, Venice (Murano), and England in the 17th century. Draw a line of time marked in centuries and name on it each of the above periods. Then in

each period draw examples of articles of glass from each period. Show when the blowpipe came into use.

4. What is flint glass? Tell how it came to be discovered and why, as a result of its development, England became a glass making country.

Chapter III

1. Draw a glass maker's chair and tools. Name and describe the use of each tool.

2. What do the following words mean? Calcar, lehr, teaser, prunt, bullion, cullet, marver, servitor, gaffer.

3. Describe the processes by which crown and broad glass were made.

4. Both Mr. Edmund Lewin and Mr. Pepys, for whom, you will remember, Mr. Lewin had made some wine bottles, were real people. Little is known of Mr. Lewin, but Samuel Pepys was quite an important person. Find out about him from books in the Junior Public Library and give a short lecture on his life.

Chapter IV

1. What part does the hand glassblower play in the modern glass industry? Why have machines not entirely replaced him?

2. What is the meaning of the following words? Fireclay, producer gas, batch, waterglass, parison, sandblasting, etching.

3. To what extent does the bottle-making machine copy the hand-making process described in the last chapter?

4. Describe the different ways of decorating glass mentioned in this book. Try to find examples of each type of decoration.

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